AFRL-HE-BR-TR-2005-0075

United States Air Force Research Laboratory

SCHEDULING AIRCREWS 2: NIGHTTIME MISSIONS

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May 2005

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REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**			
1. REPORT DATE *(DD-MM-YYYY)* May 2005	**2. REPORT TYPE** Interim		**3. DATES COVERED** *(From - To)* 1 Jun -30 Sep 2004
4. TITLE AND SUBTITLE SCHEDULING AIRCREWS 2: NIGHTTIME MISSIONS			**5a. CONTRACT NUMBER**
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) James C. Miller			**5d. PROJECT NUMBER** 7757
			5e. TASK NUMBER P9
			5f. WORK UNIT NUMBER 04
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Human Effectiveness Directorate Biosciences and Protection Division Fatigue Countermeasures Branch Brooks City-Base, TX 78235			**8. PERFORMING ORGANIZATION REPORT**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Human Effectiveness Directorate Biosciences and Protection Division Fatigue Countermeasures Branch 8248 Chennault Path Brooks City-Base, TX 78235			**10. SPONSOR/MONITOR'S ACRONYM(S)** AFRL/HE
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-HE-BR-TR-2005-0075
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			
13. SUPPLEMENTARY NOTES			

14. ABSTRACT

The objective of this Memorandum was to develop aircrew work-rest guidance that deals with the shift lag issues associated with nighttime missions; for example, scheduling night-vision-goggle training sorties. It was hoped that this guidance could be used by operational commanders to determine when best to employ their crews. The calculations in this TM were based upon the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model. The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm. This applied model was implemented in the Windows program, Fatigue Avoidance Scheduling Tool (*FAST*™, NTI Inc., Dayton OH), which was used to make the calculations and to draw the figures shown in this Memorandum. Guidance was presented for military aviation training missions by the quarter of the day. "Evening" missions generally operate within the period 1800-0000h and allow crews to accomplish their night approaches, landings and other required training, such as operations with NVGs. Occasionally, "night" missions are flown in the 0000-0600h period. Discussions were presented for flying before midnight (evening missions), flying after midnight (night missions), acclimation to permanent night missions, and re-acclimation to day work.

15. SUBJECT TERMS
Aircrew, schedules, fatigue, night work, model-based, SAFTE, FAST

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr. James C. Miller
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UNCLAS	18	**19b. TELEPHONE NUMBER** *(include area code)* 210-536-2742

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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PREFACE

This Technical Memorandum covers the project period of 1 to 30 September 2004. The work was performed under Job Order Number 7767P904. The project manager was Dr. James C. Miller, Senior Research Physiologist, Fatigue Countermeasures Branch, Biosciences and Protection Division, Air Force Research Laboratory (AFRL/HEPF).

This Technical Memorandum was written in response to aircrew fatigue problems for night work, identified to this Branch by A3 Transport Ops, 1 Canadian Air Division Headquarters, Winnipeg, MB Canada in September 2004.

This is one of several case-studies of operations produced by this Branch at the end of fiscal year 2004 using the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model[1]. SAFTE integrated the effects upon cognitive performance effectiveness of length of prior wakefulness, amount of sleep and circadian rhythm. In turn, the SAFTE applied model was implemented in the Windows® program, Fatigue Avoidance Scheduling Tool (*FAST*™, NTI Inc., Dayton OH). For this case study, we used *FAST*™ beta version 1.0.13 with the following parameter values:

Model Parameters	Values
24-hr rhythm acrophase	18
12-hr rhythm phase offset	3
Relative amplitude of 12-hr rhythm	0.5
Sleep propensity mesor	0
Sleep propensity amplitude	0.55
Maximum sleep accumulation per minute	3.4
Performance rhythm amplitude (fixed %)	7
Performance rhythm amplitude (variable %)	5
Reservoir capacity	2880
Feedback amplitude	0.0031200
Sleep inertia time constant	0.04
Maximum inertia following awakening (%)	5
Performance use rate	0.5
Slow recovery	
K1	0.22
K2	0.5
K3	0.0015
Sleep environment	
Excellent	1
Moderate	0.83
Poor	0.5

[1] Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Storm WF, Miller JC, Eddy DR. (2004). Fatigue models for applied research in warfighting. *Aviation, Space and Environmental Medicine*, 75(3), Section II, Supplement, pp. A44-A53.

SUMMARY

The objective of this Memorandum was to develop aircrew work-rest guidance that deals with the shift lag issues associated with nighttime missions; for example, scheduling night-vision-goggle training sorties. It was hoped that this guidance could be used by operational commanders to determine when best to employ their crews.

The calculations in this TM were based upon the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model. The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm. This applied model was implemented in the Windows program, Fatigue Avoidance Scheduling Tool (*FAST*™, NTI Inc., Dayton OH), which was used to make the calculations and to draw the figures shown in this Memorandum.

Guidance was presented for military aviation training missions by the quarter of the day. "Evening" missions generally operate within the period 1800-0000h and allow crews to accomplish their night approaches, landings and other required training, such as operations with NVGs. Occasionally, "night" missions are flown in the 0000-0600h period. Discussions were presented for flying before midnight (evening missions), flying after midnight (night missions), acclimation to permanent night missions, and re-acclimation to day work.

SCHEDULING AIRCREWS 2: NIGHTTIME MISSIONS

INTRODUCTION

The objective of the exercise documented here was to develop aircrew work-rest guidance that deals with the shift lag issues associated with nighttime missions; for example, scheduling night-vision-goggle training sorties. It was hoped that this guidance could be used by operational commanders to determine when best to employ their crews.

Military aviation training missions are often scheduled by the quarter of the day. "Morning" missions generally operate within the 0600-1200h period and allow operations in relatively smooth air. "Afternoon" missions generally operate within the period 1200-1800h. "Evening" missions generally operate within the period 1800-0000h and allow crews to accomplish their night approaches, landings and other required training, such as operations with NVGs. Occasionally, "night" missions are flown in the 0000-0600h period.

Experience and the applied quantitative model used here indicated that morning and afternoon sorties may usually be operated without unacceptable risks of fatigue-induced mishaps[2]. Two exceptions would be (1) morning missions that start so early (for example, a 0400h show time) that nocturnal sleep is truncated, and (2) flying both morning and afternoon sorties each day. The latter practice is more likely to induce physical fatigue and dehydration than mental acute or cumulative fatigue.

Missions scheduled for evenings can, if not managed properly, generate some unacceptable levels of fatigue. The fatigue associated with night missions is difficult to manage and, as a result, night missions are inherently risky. When scheduling crews for evening and/or night missions, the operational commander must take into account the preceding work-sleep schedule of the crew to avoid an unacceptable risk of a fatigue-induced mishap.

In the simplest case, an operational commander would schedule crews who are acclimated to the normal day-work, night-sleep cycle for a single evening mission. Crews may also need to be scheduled to fly during the midnight-to-dawn period on a single night and/or to be scheduled to fly on several sequential nights. Each of these increasingly demanding and risky scenarios is examined here and recommendations are made for night-scheduling practices, including the use of alertness aids.

No recommendations are made here for the use of pharmacological sleep aids, melatonin, or bright light therapy. Pharmacological sleep aids are highly likely to improve daytime sleep. However, good quality daytime sleep was assumed in the cases, below. Melatonin was not approved for aircrew use in the Canadian or the United States military forces at the time this memo was written. Bright light can be helpful during night work to help suppress natural, nocturnal melatonin secretion and, concomitantly, reduce sleepiness. However, aircrews cannot normally use bright light at night in the cockpit, due to requirements to see and avoid

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[2] In the context of the estimates produced by *FAST*™, a predicted value for cognitive performance effectiveness that is below 90% indicated an unacceptable risk of a fatigue-induced mishap. The 90% value is the effectiveness estimate for normal bedtime for a rested individual.

other traffic in visual meteorological conditions.[3] Bright light exposures before and after the expected sleep period may be used to phase delay and phase advance, respectively, one's circadian rhythms. However, in the absence of real-time, accurate knowledge of the expected sleep period, there is a substantial risk that poorly-timed bright light exposures will aggravate shift lag.

METHODS

The calculations in this TM were based upon the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model. The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm. This applied model was implemented in the Windows program, Fatigue Avoidance Scheduling Tool (*FAST*™, NTI Inc., Dayton OH), which was used to make the calculations and to draw the figures shown in this Memorandum.

The *FAST*™ graphs in this TM depict a cognitive effectiveness prediction (left-hand vertical axis) as a function of time (horizontal axis). Work periods are shown as red bands on the horizontal axis and reflected up as wider red portions on the cognitive effectiveness prediction. Sleep periods are shown as blue bands across the horizontal axis.

The cognitive effectiveness prediction is for composite human performance on a number of cognitive tasks such as logical reasoning and mental arithmetic. The prediction (left-hand) axis is scaled up to 100%. The oscillating black and red line in the diagram represents expected group average performance (throughput) on cognitive tasks. We would expect the predicted performance of half of the people in a group to fall below this line.

The green area on the chart ends at the time for normal sleep, about 90% effectiveness. Our goal is to keep operation above this line during safety-sensitive work such as flying, driving, operating weapons, and making command and control decisions. The red area on the chart represents performance effectiveness after 2 days and a night of sleep deprivation. Workers in this area are highly likely to fall asleep on the job.

The thin red line is referenced to the right-hand vertical axis, scaled from 0001h at the bottom, through noon to midnight at the top. This plot shows the process of re-alignment of the body's circadian rhythm phase with the day-night cycle in the new time zone.

[3] R&D should be directed toward the use of bright light at night in the cockpit while flying continuously in instrument meteorological conditions.

FLYING BEFORE MIDNIGHT (EVENING MISSIONS)

Many shiftworkers report that the "swing" shift (for example, 1500-2300h) is the easiest shift to work in a 3-shift schedule. The two leading reasons advanced for this statement are (1) the general absence of management attention after normal office hours and (2) the ability to acquire a good night of sleep after the end of the shift. The latter reason applies also to scheduling aircrews for evening missions (nominally, 1800-0000h). The availability of a long, nocturnal sleep period can, if the period used for sleep, sharply reduce the risk of fatigue-induced errors during evening flights.

A best practice in the scheduling of rotating 3-shift systems is to always rotate workers to shifts that are later on the clock ("clockwise"). In the present case, that would mean rotating a morning crew to afternoon missions before rotating them to evening missions. This method of rotation is not usually practical in military aviation operations. As a result, there is a penalty in evening mission length that one must pay for morning crews. We have examined two likely, clockwise rotations here: morning-evening-morning and afternoon-evening-afternoon. In each case, we have considered both the single evening mission and a 5-day week of evening missions.

AFTERNOON-EVENING-AFTERNOON

We selected the period 2200h to 0600h (and acrophase 1800h) as the likely, expected sleep period for afternoon crews. The SAFTE model predicted that people who usually sleep from 2200h to 0600h will remain above 90% cognitive performance effectiveness throughout the day, from 0600h until 2200h. Thus, the commander may expect that mission termination by 2200h for a single evening mission by an afternoon crew will result in an acceptably low risk of a fatigue-induced mishap (Figure 1, evening of Day 1).

For subsequent sequential evening missions, the crews will (and should) tend to slip their sleep to a later period (for example, sleeping from 0100h to 0900h) and their body clock will (and should) delay its phase (represented as acrophase time; Figure 2). Mission termination by 2245h on the second sequential evening and by 2330h on the third sequential evening should also result in an acceptably low risk of a fatigue-induced mishap (as in Figure 2, evenings of Days 1 and 2).

For the situation in which an afternoon crew flies five sequential evening missions, the circadian phase advance back to an "afternoon" schedule with occurs within the two days of the weekend (Figure 2).

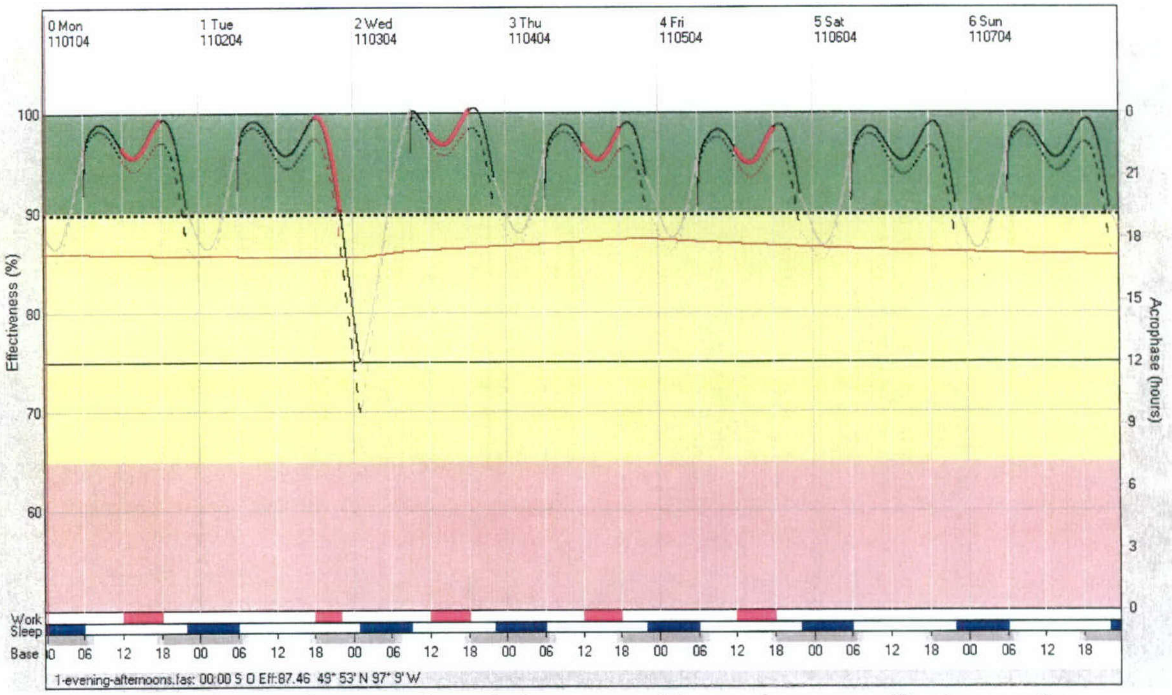

Figure 1. Effects of one evening mission on cognitive performance effectiveness for afternoon crews. Red bars on the abscissa are mission periods (reflected up to the performance effectiveness estimate) and blue bars are sleep periods. The thin red line (crossing the yellow area in this graph) represents the change in acrophase time, scaled as clock hours on the right-hand ordinate. The dashed line below the estimate represents 10 percentile points below the estimated mean.

Recommendations for Evening Missions Flown by Afternoon Crews

- Terminate evening missions by 2200h, 2245h, and 2330h on evenings 1, 2 and 3, respectively, and by 0000h subsequently.
- Specify the sleep period for crew rest during sequential evening missions as 0100h to 0900h.

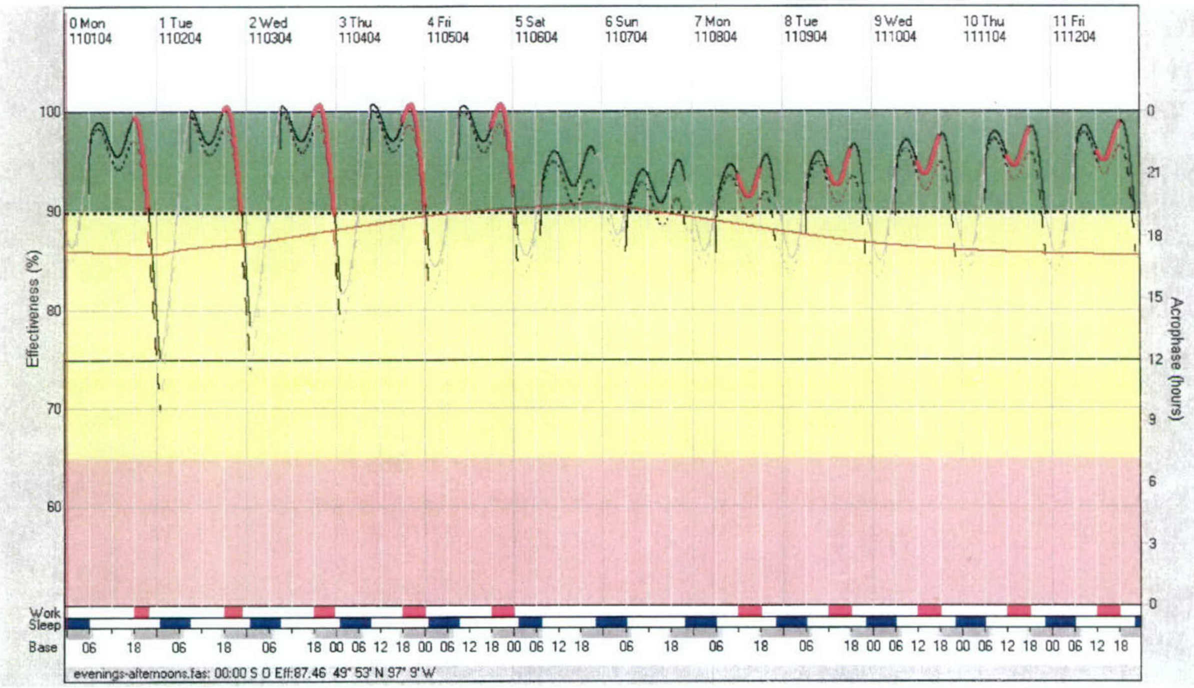

Figure 2. Effects of 5 evening missions and then 5 afternoon missions on cognitive performance effectiveness across 2 weeks.

MORNING-EVENING-MORNING

We selected the period 2100h to 0500h (and acrophase 1700h) as the likely, expected sleep period for morning crews. The SAFTE model predicted that people who usually sleep from 2100h to 0500h will remain above 90% cognitive performance effectiveness throughout the day, from 0500h until 2100h. Thus, the commander may expect that mission termination by 2100h for a single evening mission will result in an acceptably low risk of a fatigue-induced mishap (Figure 3, evening of Day 1).

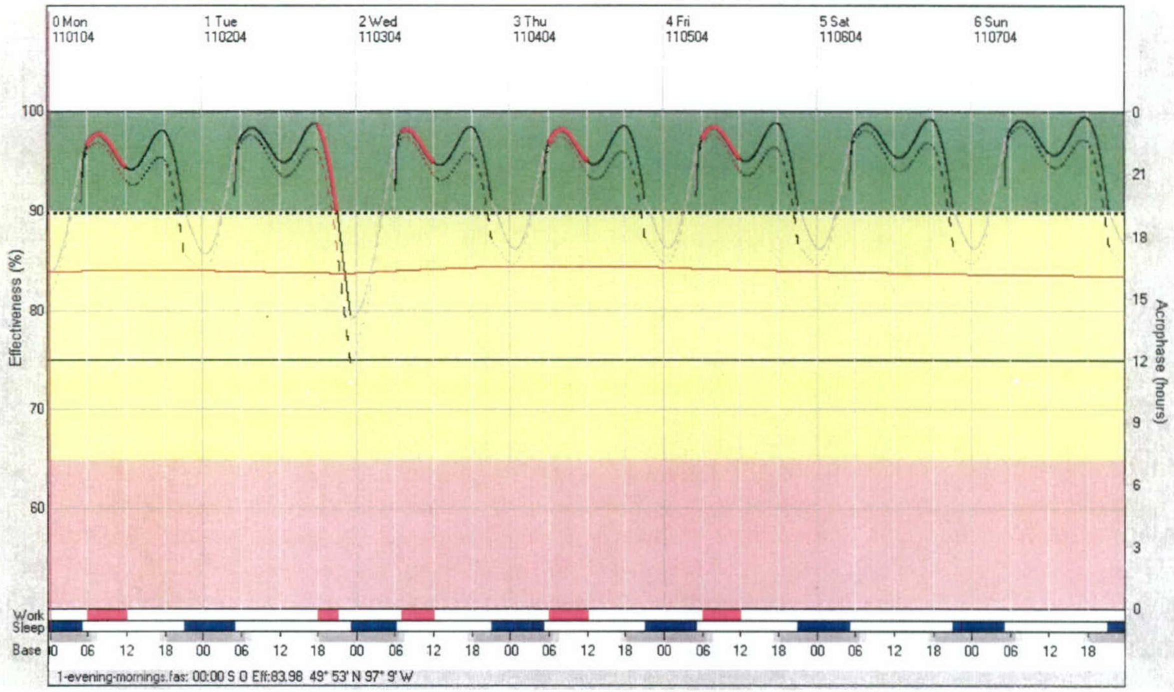

Figure 3. Effects of one evening mission on cognitive performance effectiveness for morning crews.

For subsequent sequential evening missions, the crews will (and should) tend to slip their sleep to a later period (for example, sleeping from 0100h to 0900h) and their body clock will (and should) delay its phase (represented as acrophase time; Figure 4). Mission termination by 2145h on the second sequential evening, by 2230h on the third sequential evening and by 2315 on the fourth sequential evening should also result in an acceptably low risk of a fatigue-induced mishap (as in Figure 4, evenings of Days 1, 2 and 3).

The recommended evening mission termination times across morning and afternoon crews allows a generalization: mission termination on the first night of evening flying should occur at the expected bedtime for morning or afternoon flying, which ever is applicable. On subsequent evenings, mission termination time may slip 45 minutes later each evening.

For the situation in which a morning crew flies five sequential evening missions, the circadian phase advance back to a morning schedule takes a little longer than the 2-day weekend (Figure 4). This problem can be dealt with by assuring that the first morning's take-off does not occur until 0800h or later and that the second morning's take-off does not occur until 0645h or later (as in Figure 4).

Recommendations for Evening Missions Flown by Morning Crews

- Terminate evening missions by 2100h, 2145h, 2230h and 2345h on evenings 1, 2, 3 and 4, respectively, and by 0000h subsequently.
- Specify the sleep period for crew rest during sequential evening missions as 0100h to 0900h.

- After five sequential evening flights, allow two days of rest and then delay take-offs for morning missions until 0800h and 0645h on the first and second mornings of flying, respectively.

<u>Generalized Recommendation for Evening Missions</u>

- Terminate evening missions by expected bedtime. On subsequent evenings, mission termination time may slip 45 minutes later each evening up to midnight.

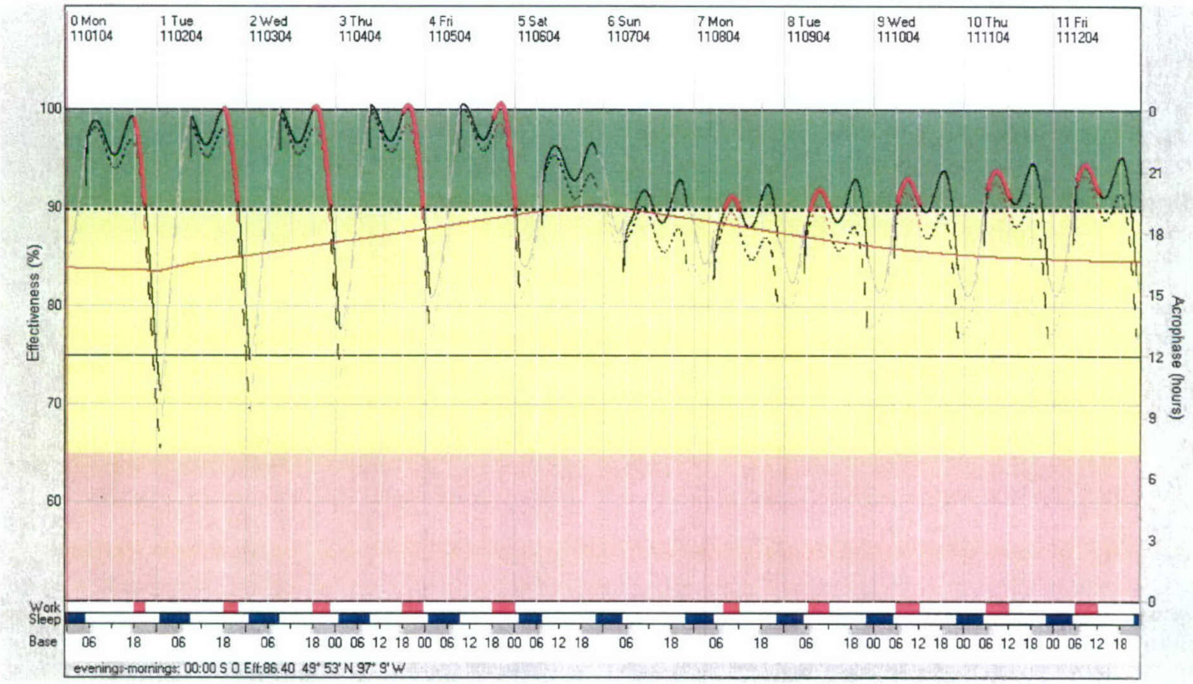

Figure 4. Effects of 5 evening missions and then 5 morning missions on cognitive performance effectiveness across 2 weeks.

FLYING AFTER MIDNIGHT (NIGHT MISSIONS)

Many shiftworkers report that the "night" or "graveyard" shift (for example, 2300-0700h) is the most difficult shift to work in a 3-shift schedule. The two leading reasons advanced for this statement are (1) the inability to acquire nocturnal sleep and (2) the pre-dawn nadir in metabolic activity. These two reasons also apply to the scheduling of aircrews for night missions (nominally, 1800-0000h). Both the lack of a nocturnal sleep period and the pre-dawn nadir sharply elevate the risk of fatigue-induced errors during night flights in an additive manner.

AFTERNOON-EVENING-AFTERNOON

Again, we selected the period 2200h to 0600h (and acrophase 1800h) as the likely, expected sleep period for afternoon crews. SAFTE predicted that, during the single night mission, the crew's cognitive performance effectiveness would hit a nadir of 73% at 0400h and still be at only 75% at 0600h, the end of the work period (Figure 5, morning of Day 2).

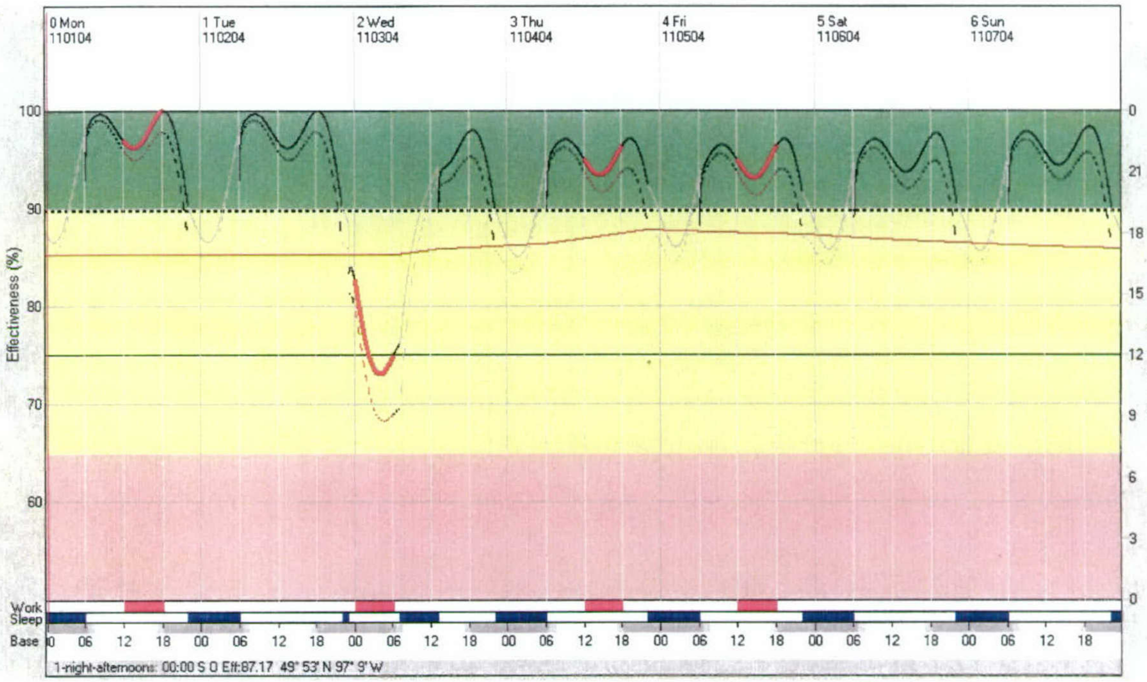

Figure 5. Effects of one night mission on cognitive performance effectiveness for afternoon crews.

This is a situation in which the primary fatigue countermeasure, sleep, is necessary but not sufficient. Additional countermeasures are needed to elevate cognitive performance effectiveness to an acceptable level. These might include the tactical use of caffeine[4] or medically-prescribed modafinil (Provigil®) or dextroamphetamine (Dexedrine®), in accord with approved policies.

[4] Limit daily caffeine consumption to 250 mg or less so that it is an effective countermeasure when needed.

For subsequent sequential evening missions, the crews will (and should) nap before night flying and their body clock will (and should) delay its phase (represented as acrophase time; Figure 5). Again, this is a situation in which the primary fatigue countermeasure, sleep, is necessary but not sufficient. Additional countermeasures are needed to elevate cognitive performance effectiveness to an acceptable level.

For the situation in which an afternoon crew flies five sequential night missions, the circadian phase advance back to an afternoon schedule requires five days, during which flying is not recommended without additional countermeasures, even during afternoon missions (Figure 5).

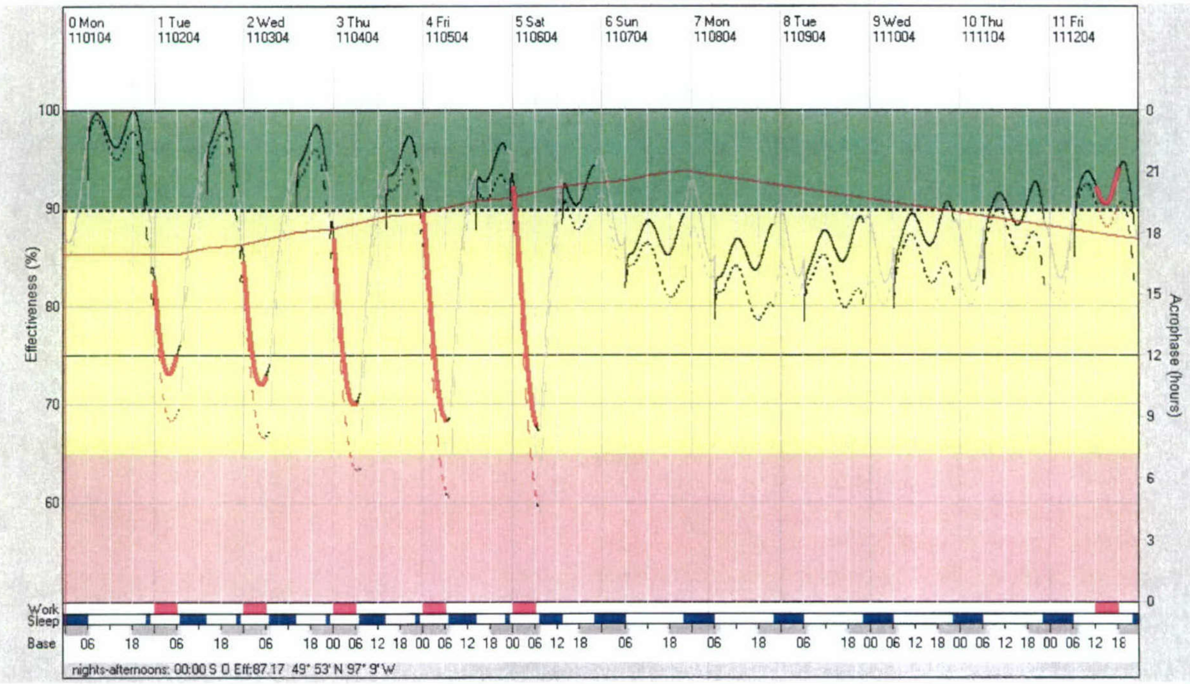

Figure 6. Effects of 5 night missions on afternoon crews' cognitive performance effectiveness across 2 weeks.

Recommendations for Night Missions Flown by Afternoon Crews

- The primary fatigue countermeasure, sleep, is necessary but not sufficient. Additional countermeasures are needed to elevate cognitive performance effectiveness to an acceptable level.
- After five sequential night flights, allow five days of rest.

MORNING-NIGHT-MORNING

Again, we selected the period 2100h to 0500h (and acrophase 1700h) as the likely, expected sleep period for morning crews. SAFTE predicted that, during the single night mission, the crew's cognitive performance effectiveness would hit a nadir of 72% at 0300h and still be at only 74% at 0600h, the end of the work period (Figure 7, morning of Day 2).

This also is a situation in which the primary fatigue countermeasure, sleep, is necessary but not sufficient. Additional countermeasures are needed to elevate cognitive performance

effectiveness to an acceptable level. These might include the tactical use of caffeine[5] or medically-prescribed modafinil (Provigil®) or dextroamphetamine (Dexedrine®), in accord with approved policies.

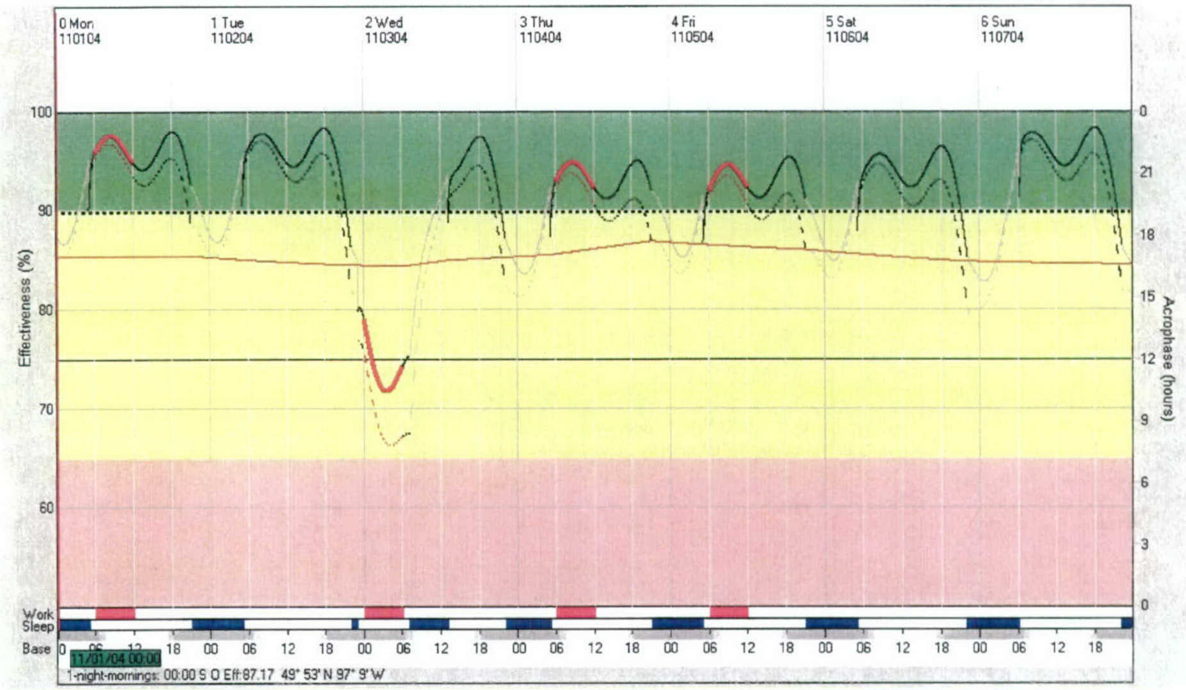

Figure 7. Effects of one night mission on cognitive performance effectiveness for morning crews.

For subsequent sequential evening missions, the crews will (and should) nap before night flying and their body clock will (and should) delay its phase (represented as acrophase time; Figure 8). Again, this is a situation in which the primary fatigue countermeasure, sleep, is necessary but not sufficient. Additional countermeasures are needed to elevate cognitive performance effectiveness to an acceptable level.

For the situation in which a morning crew flies five sequential night missions, the circadian phase advance back to a morning schedule requires six days, during which flying is not recommended without additional countermeasures, even for morning missions (Figure 8).

Recommendations for Night Missions Flown by Morning Crews

- The primary fatigue countermeasure, sleep, is necessary but not sufficient. Additional countermeasures are needed to elevate cognitive performance effectiveness to an acceptable level.
- After five sequential night flights, allow six days of rest.

[5] Limit daily caffeine consumption to 250 mg or less so that it is an effective countermeasure when needed.

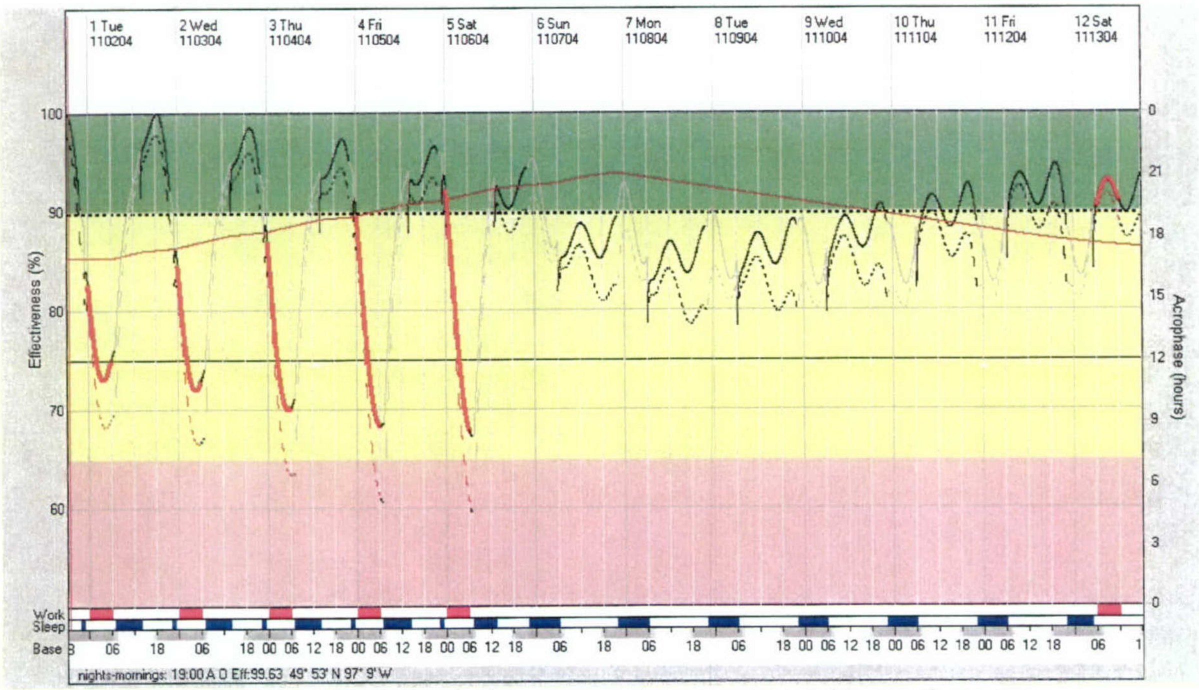

Figure 8. Effects of 5 night missions on morning crews' cognitive performance effectiveness across 2 weeks.

ACCLIMATION TO PERMANENT NIGHT MISSIONS AND SHIFT LAG

For the most general approach to this problem, imagine a crew that usually sleeps from 2200h to 0600h. Suddenly, the crew must instead work from 2200h to 0600h with no nights of sleep. Daytime sleep is required for acclimation to night work. The crew would not fly every night. However, to acclimate to night work, they must acquire their major sleep period sleep in each and every daytime period.

Additionally, imagine the best-case sleep scenario: the person is successful at sleeping after work from 0700h to 1500h[6]. Even in this best-case scenario, the acclimation of the crew's circadian rhythms to the inverted work-rest cycle[7] takes many days (Figure 9).

Inspection of the metrics associated with Figure 9 shows that the first half of half of the work period is spent below 90% cognitive effectiveness until the 13th sequential night shift. Thus, missions extending past 0200h could not be flown safely until the 3rd week of this night shift. Missions extending until 0600h could not be flown safely until the end of the 3rd week of the shift.

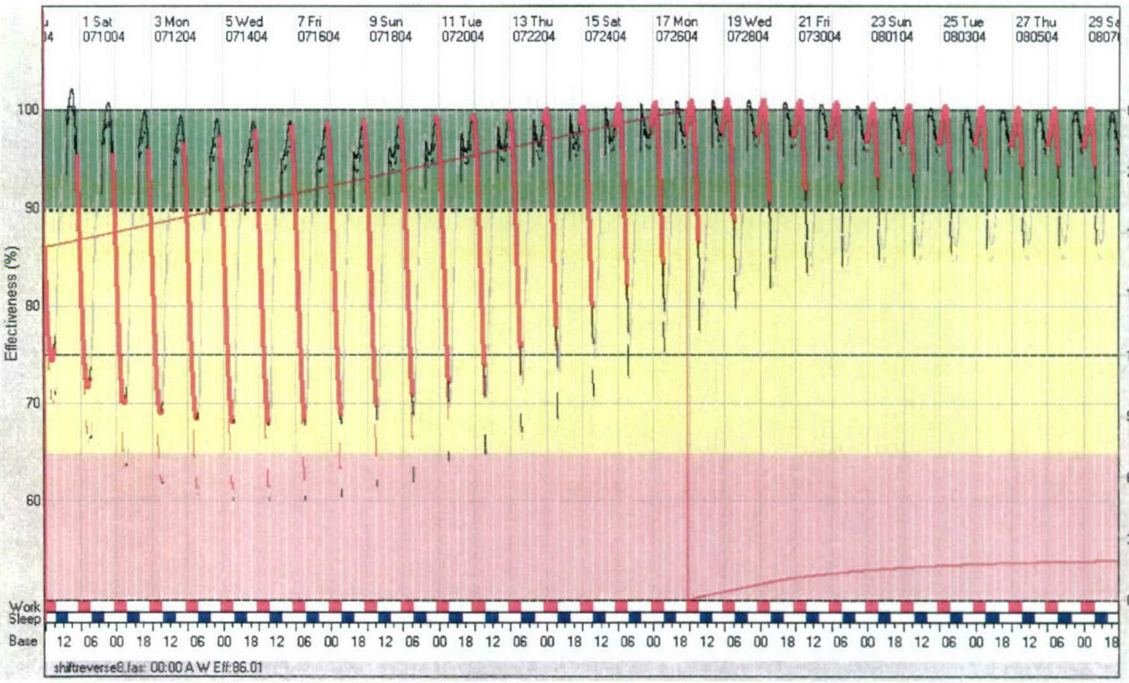

Figure 9. Effects of a 12-hour work shift change on cognitive performance effectiveness across 30 days, with theoretical work periods every night.

Given a month of dedicated effort by crews and management, it may be possible to acclimate crews to night work. Management's role is to provide administrative and sleep hygiene support. The crew's role is to take advantage of management support to sleep only during the daytime hours, whether or not they are scheduled to fly that night.

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6 Most people need pharmacological sleep aids to sleep this well during the day.

7 In fact, without aggressive attention to sleep hygiene and the sleep environment, very few workers' circadian rhythms acclimate fully to a day-sleep—night-work schedule.

What happens if a crew decides to reverse their sleep-wake pattern (to nocturnal sleep) for one weekend when they are not scheduled to fly at night? They lose about a week's worth of acclimation to night work (Figure 10).

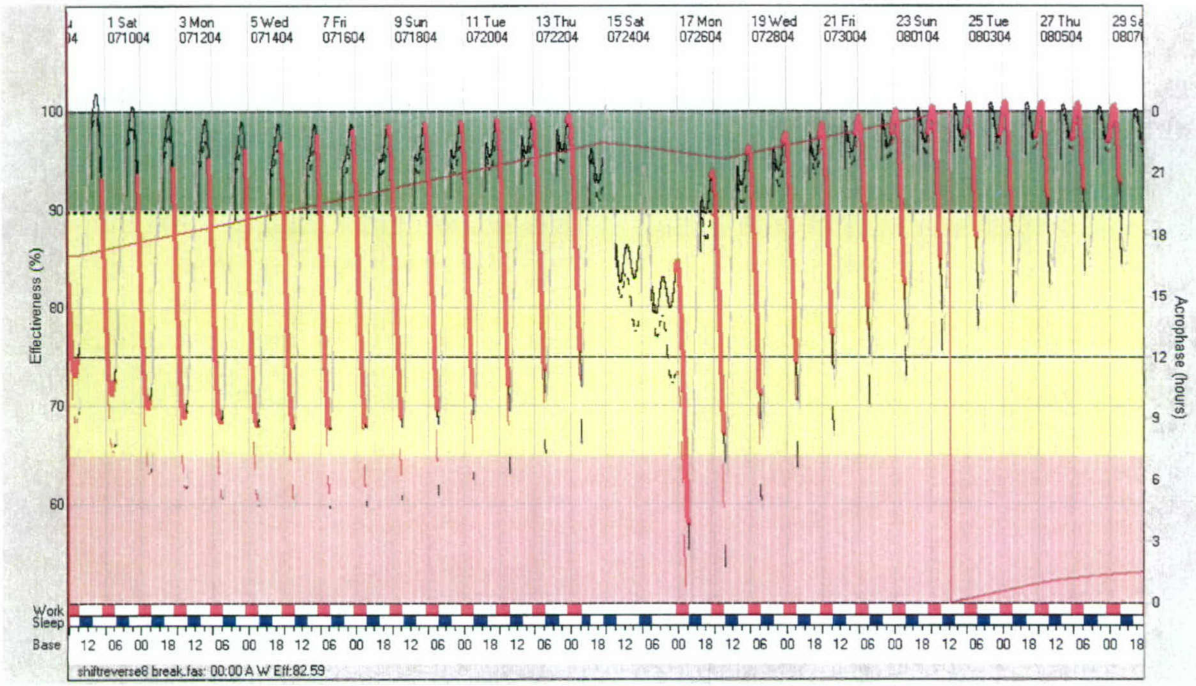

Figure 10. Effects of a 12-hour work shift change on cognitive performance effectiveness across 30 days. Theoretical work periods every night except during one weekend, when nocturnal sleep is acquired.

<u>Recommendations for Permanent Assignment to Night Flying</u>

- Acclimating Crew
    - First week: Extend mission termination time by no more than 45 minutes per night from normal bedtime through 0000h.
    - Second week: Extend mission termination time by no more than 45 minutes per night from 0000h through 0400h.
    - Third week: Extend mission termination time by no more than 45 minutes per night from 0400h through dawn.
    - If a crew reverts to nighttime sleep for one night, do not allow them to fly the next night. Then add one week to the acclimation process.
    - If a crew reverts to nighttime sleep for two sequential nights, start the acclimation process over.
- Fully Acclimated Crew
    - If a crew reverts to nighttime sleep for one night, do not allow them to fly the next night. Then, terminate the next night's mission by 0500h.
    - If a crew reverts to nighttime sleep for two nights, do not allow them to fly the next night. Then, terminate the next two night's missions by 0400h and 0500h, respectively.

RE-ACCLIMATION TO DAY WORK (SHIFT LAG)

The pattern of change in cognitive effectiveness is somewhat different for the re-acclimation from night work back to day work, compared to the original acclimation to night work (Figure 11). If we change the crew shown in Figure 9 back to day work (07-1500h) and night sleep (22-0600h), it may take 30 days before all of the work period is spent at 90% cognitive performance effectiveness or above. Caveat: The software forced a phase advance for this re-acclimation period. If, in fact, a phase delay occurs then recovery may occur in about 21 days. We have no data that would allow us to determine which direction the body clock takes in this case.

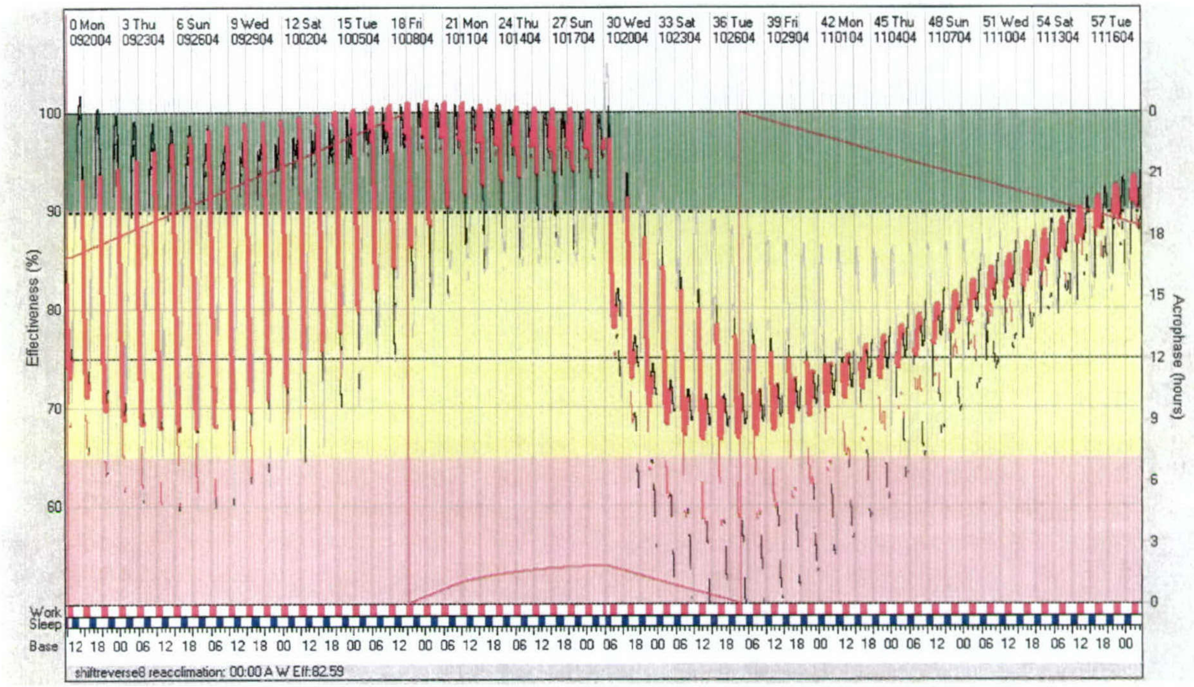

Figure 11. Effects of two 12-hour work shift changes on cognitive performance effectiveness across 60 days. Theoretical work periods every night (22-0600h) and daytime sleep (07-1500h) for 30 days, and then theoretical work periods every day (07-1500h) and nocturnal sleep (2-0600h) for 30 days.

Recommendations for Re-Assignment to Day Flying from Permanent Night Flying

- Allow 30 days of non-flying recovery